RUNNING HEAD: The SNARC effect in L2

The SNARC effect in the processing of second language number words: Further evidence for strong lexico-semantic connections

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Abstract

We present new evidence that word translation involves semantic mediation. It has been shown that participants react faster to small numbers with their left hand and to large numbers with their right hand. This SNARC effect is due to the fact that in Western cultures the semantic number line is oriented from left (small) to right (large). We obtained a SNARC effect when participants had to indicate the parity of L2 number words, but not when they had to indicate whether L2 number words contained a particular sound. Crucially, the SNARC effect was also obtained in a translation verification task, indicating that this task involved the activation of the number magnitude.

Key words: bilingualism; word translation; semantic; lexical; SNARC effect; number words; Revised Hierarchical Model

Introduction

As ~~most~~ a lot of people have knowledge of two or even more languages, ~~bilingualism is the rule rather than the exception. Consequently,~~ there is an increasing interest in research on the cognitive processes involved in translation from the first language (L1) to the second language (L2) (forward translation) and from L2 to L1 (backward translation). One of the main questions is to what extent these translations are based on word-word associations and to what extent they require semantic mediation. In general, researchers have put more emphasis on word-word associations than on semantic mediation, in particular for backward translation. Only recently has this view become challenged.

The organization of the introduction is as follows. First, we present the dominant model of word translation. Then, we summarize the evidence pointing to a pivotal role of semantic mediation. Finally, we indicate why number translation can shed further light on the issue by looking at the SNARC effect.

The Revised Hierarchical Model of Bilingualism

The dominant view of bilingual word representation and word translation is the Revised Hierarchical Model (RHM) of Kroll and Stewart (1994; see also Kroll & de Groot, 1997). In this model, L1 and L2 words are represented in two separate lexicons that access a common conceptual system ~~(Figure 1)~~. There are connections between the word forms that are each other's translations, and between the word forms of each language and the underlying meaning of the words. It is further assumed that the word-word connections are stronger from L2 to L1 than from L1 to L2, because L2 words are essentially learned by associating them with their translation. It is also assumed that the connections from L1 to the semantic system are stronger than those from L2 to the semantic system, up to a very high level of L2 proficiency. Evidence for this asymmetry was reported, for instance, by Sholl, Sankaranarayanan and Kroll (1995). They showed that pictures of words which had to be translated later in the experiment were effective primes in forward, but not in backward translation, suggesting a bigger involvement of semantic information in forward translation than in backward translation. Similar asymmetric semantic effects in translation tasks have been reported by Kroll and Stewart (1994) and Cheung and Chen (1998; see also Kroll & de Groot, 1997 and Kroll & Tokowicz, 2005, for reviews of evidence supporting the RHM).

~~(Figure 1 about here)~~

Much of the criticism against the RHM has focused on the question whether L1 and L2 word forms are stored in separated lexicons or constitute a unitary lexicon (e.g., Brysbaert, 1998; Brysbaert & Dijkstra, 2006; for a review, see Dijkstra & Van Heuven, 2002). The consensus is growing that there is more evidence for a single lexicon than for two distinct lexicons, as has also been acknowledged by Kroll in later writings (e.g., Kroll & Dijkstra, 2002). So, a more accurate representation of the current ideas about the RHM would look like the model presented in Figure 2. This model also takes into account the fact that the meanings of translation equivalents are rarely completely the same. This is done by assuming that words activate semantic features, rather than unitary concepts (Kroll & de Groot, 1997), similar to the way semantic representations are conceived in the distributed feature model of de Groot and colleagues (e.g., de Groot, 1992; Van Hell & de Groot, 1998).

(Figure 2 about here)

A bigger role for the semantic system in word translation?

Because of the asymmetry of the connections in RHM, the basic message from the model has been that backward translation often is non-semantic, purely based on the strong lexical connections from L2 words to their L1 translations, up to a high level of L2 proficiency. Because of the strong links between L1 word forms and meaning, the model predicted more semantic involvement in forward translation.

La Heij, Hooglander, Kerling and Vandervelden (1996) were among the first to question the non-semantic nature of backward translation. They found that participants translated a word faster if on top of the word there was a picture representing its concept (e.g., a picture of a dog when the word DOG had to be translated) than when a picture of an unrelated concept was presented (e.g., a picture of an axe when the word DOG had to be translated). Importantly, the facilitation effect was found both for backward and forward translation and was of the same magnitude, suggesting that semantic mediation was involved to the same extent in both tasks. Altarriba and Mathis (1997) reported a similar effect with monolingual participants who were trained on a set of English-Spanish word pairs and consequently had a very low level of L2 proficiency.

Duyck and Brysbaert (2004; see also Duyck & Brysbaert, 2002) reported another semantic effect in backward translation for low proficiency levels. They made use of the number magnitude effect to investigate semantic mediation in number translation. The number magnitude effect implies that large numbers take longer to activate their meaning than small numbers (Brysbaert, 1995). Duyck and Brysbaert (2004) showed that participants needed more time to translate the number word ‘nine’ than the number ‘three’. Importantly, the effect was found both in forward and backward translation and again at very low levels of proficiency (i.e., it was also observed for participants who learned the L2 number words at the beginning of the experiment).

In order to reconcile these findings with the earlier research supporting the RHM, Duyck and Brysbaert (2004) proposed a connectionist model (see Figure 3), which differs from the RHM in a number of ways.

(Figure 3 about here)

First, the relative contribution of the lexical and semantic routes for translation is no longer an all-or-none process. Instead, activation of the units in the model increases or decreases over processing cycles. In each cycle, there is activation both from the direct word-word connections and from the semantically mediated connections. The relative weights of the two routes depend on the change of activation they introduce on each cycle. Secondly, the asymmetry of the weights of the two routes in the model depends not only on the proficiency of the bilingual, but also on the word type. The contribution of the semantic route will be stronger for words that have very similar meanings in both languages (e.g., concrete nouns, number words) than for words that have less overlapping meanings (e.g., abstract nouns, adjectives).

In the present study we test Duyck and Brysbaert’s (2002, 2004) claim that semantic mediation always plays a role in number translation, by making use of another semantic effect in numerical cognition, the SNARC effect. As we will see, this effect is particularly interesting because it allows us to show with a single technique the existence of a non-semantic route for word naming and the involvement of semantics in meaning-related tasks.

The SNARC Effect

Dehaene, Bossini, and Giraux (1993) showed that in a number parity task, participants react faster with the left hand to small numbers and with the right hand to large numbers. They called this effect the SNARC effect (Spatial-Numerical Association of Response Codes; for reviews, see Fias & Fischer, 2005; Gevers & Lammertyn, 2005) and attributed it to the fact that in Western cultures, the small numbers are placed on the left hand side of ~~the~~ a mental number line and large numbers on the right hand side. This results in a kind of stimulus-response compatibility effect: responses are faster when the response side agrees with the position on the number line than when it does not.

The SNARC effect gained additional interest, when it was discovered that it is also found in situations that do not explicitly require access to the meaning of the numbers. Fias, Brysbaert, Geypens, and d'Ydewalle (1996) showed that the SNARC effect is also obtained when participants have to indicate whether the name of an Arabic digit includes a certain sound or not. So, participants were faster to indicate with their left hand than with their right hand that the digit 2 contained a /t/ sound, whereas they responded faster with their right hand than with their left hand when the same decision had to be made about the digit 8. Fias et al. (1996) interpreted this finding as evidence that digits require semantic mediation to activate their pronunciation.

In a later study, Fias (2001) showed that the SNARC effect was not found when participants had to indicate whether a number word contained a particular sound or not. So, there were no differences in RTs between the left and the right hand, when participants had to indicate whether the words ‘two’ and ‘eight’ contained a /t/ sound. He interpreted this finding as evidence that orthography-phonology conversions do not require semantic mediation, in line with many existing models of word naming (e.g., Coltheart et al., 2001).

The research by Fias and colleagues suggests that the SNARC effect provides an interesting approach to study the issue of semantic mediation in number translation. With number words, the effect is found when the number meaning is relevant (parity judgment) and not when the meaning is assumed not to be involved (phoneme monitoring~~word naming~~). This opens the way to examine where on the continuum number translation is situated: More towards the non-semantic ~~number~~ phoneme monitoring~~word naming~~ or more towards the semantic parity judgment? To find out, we first investigated whether we could replicate Fias’s findings in L2, given that all findings on the SNARC effect thus far have been limited to the participants’ native language.

Experiment 1

In previous research, the SNARC effect has been obtained in number parity tasks both with French and Dutch stimulus words (Dehaene et al., 1993, Experiment 8; Fias, 2001, Experiment 1). Importantly, in all studies so far the words have been presented in the participants’ native language. Here, we examine whether we obtain a SNARC effect when unbalanced Dutch-French bilinguals have to make a parity decision to French (L2) number words.

Method

Participants

Twenty Dutch speaking first-year psychology students (4 male, 16 female) participated for course credit. All participants were native Dutch speakers and mainly used this language in everyday life. They all started to learn French at elementary school. They reported having acquired their first French words at an average age of 8.7 years (*SD* = 2.3 years). Average age was 19.3 years (*SD* = 1.2 years). Three participants were left-handed.

Instructions

Participants were asked to judge the parity of written French number words by pressing a button with the left or right hand. They were explicitly informed about the range of the numbers and both speed and accuracy were emphasized.

Stimuli

The numbers ranged from 3 to 10. They were presented as written French number words ("trois", "quatre", "cinq", "six", "sept", "huit", "neuf" and "dix"). In this range half of the numbers is even and half contains an /s/ sound. In this way, we will be able to use the same stimuli in Experiment 2, where a phoneme monitoring task will be used.

Apparatus

All number words were presented on a standard color computer monitor with the use of the ERTS experimental software (Beringer, 1999). Reaction times were measured by means of a response box that was connected to the game port of the PC through an Exkey Logic Box.

Design

The experiment had a full factorial 2 (Parity: Odd or Even) x 2 (Side of Response: Left or Right) x 8 (Number magnitude: 3-10) design. All variables were manipulated within subjects.

Procedure

We tried to keep the procedure as close as possible to that of Fias (2001). Participants had to go through two blocks: one in which even numbers were assigned to the left hand and odd numbers to the right hand, and one block in which this response mapping was reversed. The order of both blocks was counterbalanced across participants. Each block started with a practice session in which each number within the stimulus range was presented once. In each response mapping block, all eight number words were presented 20 times each. As a result, each block consisted of 160 trials. Order was randomized within each block, but repetition of the same number on two subsequent trials was avoided. Stimuli were presented in yellow against a dark grey background as 16 points sized characters in the standard ERTS font. A trial started with an empty rectangular frame (48.9 mm x 24.8 mm) presented in the center of the screen for 300 ms. Then the target word appeared for 1300 ms or until a response was given. The screen was erased before the inter-trial interval of 1500 ms.

Results

Average error rate was 5.9 %. There was no speed-accuracy trade-off, as indicated by the positive correlation between reaction time and number of errors, computed over the 16 cells of the design (8 numbers, separately for left and right responses), $r = 0.67$, $n = 16$, $p < .01$. Overall mean response time of all correct responses was 596 ms. Following

Dehaene et al. (1993), we checked for the presence of a SNARC effect by evaluating the interaction between number magnitude and side of response in a 2 (parity: odd or even) x 2 (side of response: left or right) x 4 (number magnitude: 3-4, 5-6, 7-8, 9-10) ANOVA on the medians of the correct responses. This effect was significant, $F(3, 57) = 5.09$, $MSE = 732$, $p < .01$ ~~(Figure 4)~~.

~~(Figure 4 about here)~~

Following the standard SNARC analysis procedure (e.g., Fias et al., 1996; Fias, 2001) we used a regression analysis to evaluate the SNARC effect in more detail. Because the SNARC effect arises from an association between side of response and the position of the number on the left-to-right oriented number line, a negative relation between number magnitude and the difference in reaction time between right-hand responses and left-hand responses (dRT) is expected. Left-hand responses will be faster on small numbers, resulting in a positive dRT, while right-hand responses will be faster on large numbers, resulting in a negative dRT. In the case that a majority of the participants is right-handed, a SNARC effect can also be present if all dRTs are negative. This means that overall, right-hand responses are faster and that the SNARC effect consists of a modification of this advantage as a function of the number magnitude. Following earlier studies (e.g. Fias et al., 1996; Fias, 2001), we made use of the regression analysis for repeated measures data as recommended by Lorch and Myers (1990; see Fias et al., 1996, for a more detailed explanation of the method).

In the first step, we computed median reaction times of the correct responses, for each number and for all participants, separately for left and right responses. On the basis of these medians, we computed dRTs by subtracting the median reaction time for the left-hand responses from the median reaction time for the right-hand responses. In the second step, for each participant a multiple regression analysis on the dRTs was run with number magnitude as the predictor variable. In the third step, t-tests were done to see whether the regression weight of the number magnitude differed significantly from zero. Figure 5 shows the dRTs as a function of the magnitude of the stimulus. As can be seen, there was a negative correlation between the difference in RT between right and left hand (dRT) and number magnitude, which corresponds to ~~as predicted by~~ the SNARC effect. Most importantly, the coefficient of number magnitude differed significantly from zero, $t(19) = -3.19$, SD = 6.85, $p < .01$.

(Figure 5 about here)

To make sure that the SNARC effect was present throughout the complete range of RTs, we followed Fias's (2001) recommendation and split the data of each participant in the faster and the slower half. We then calculated the regression lines for the fast and the slow responses. These were the results:

Fast half: dRT = 25.5 – 3.3 number magnitude (RT = 505 ms)

Slow half: dRT = 68.3 – 9.0 number magnitude (RT = 651 ms)

The negative slope was significant both for the fast ($t(19) = -2.17$, SD = 6.73, $p < .05$) and the slow RTs ($t(19) = -3.61$, SD = 11.11, $p < .01$), although the slope was more distinct for the slow trials; $t(19) = 2.64$, SD = 9.66, $p < .05$.

Discussion

We obtained a SNARC effect when Dutch-French bilinguals judged the parity of French number words: Responses to small numbers were faster with the left hand, whereas responses to large numbers were faster with the right hand. This is in line with the monolingual studies of Dehaene et al. (1993) and Fias (2001) who observed a SNARC effect with L1 French and Dutch number words respectively in the same task. Although we should be cautious about comparisons across experiments, comparing the regression coefficients of number magnitude can be indicative of the strength of the SNARC effect. Fias et al. (1996) reported a weight of -7 in the same task but with Arabic numerals as stimuli, and Fias (2001) reported a weight of -3.5 in the same task with Dutch number words (-2.6 on the fast trials and -3.0 on the slow trials). We obtained a weight of -4.9 with French L2 number words, suggesting that the SNARC effect with L2 number words is not smaller than the one found with L1 number words. Further, it is interesting to note that the overall mean response time in our experiment (596 ms) was in the range reported by Fias (2001, Experiment 1) for Dutch-French bilinguals responding to L1 number words (530 ms - 630 ms). This makes it unlikely that the participants needed a translation to L1 to decide about the parity of the L2 number words.

Experiment 2

In Experiment 1, we showed that the SNARC effect is very similar in L2 as in L1 when a parity judgment task is used. This was expected given that parity judgment requires access to the semantic information. In the present experiment, we investigate whether participants are able to name visually presented L2 words without semantic mediation (see Van Wijnendaele & Brysbaert, 2002, for a comparison of word naming in

L1 and L2). To do this, we repeated the phoneme monitoring task, used by Fias (2001). Participants had to indicate whether a written word contained a certain sound or not. Importantly, this task could not be done on the basis of a simple letter-sound conversion, as will be explained in the stimulus section.

Method

Participants

The same students that participated in Experiment 1, participated in this Experiment. Half of them started with Experiment 1, the other half with Experiment 2.

Instructions

Participants were asked to judge whether the presented French number word had an /s/ sound in it by pressing one of two response buttons. Subjects had to go through two blocks, which differed with respect to the left-right response mapping. The order of the blocks was counterbalanced across participants. They were explicitly informed about the range of the numbers. Speed and accuracy were emphasized.

Stimuli

Stimuli were the same as in Experiment 1. The /s/ sound is present in ‘cinq’ (5), ‘six’ (6), ‘sept’ (7) and ‘dix’ (10) and absent in ‘trois’ (3), ‘quatre’ (4), ‘huit’ (8) and ‘neuf’ (9). This was explicitly mentioned in the instructions. The number word ‘trois’ (3, [trwa]) contains the letter ‘s’ but not the /s/ sound. Similarly, the numbers ‘cinq’ and ‘dix’ contain the /s/ sound but not the letter ‘s’. Consequently, the task could not be performed on the basis of a simple letter search; the number words had to be converted to their spoken form.

Apparatus, Design and Procedure

Apparatus, as well as design and procedure were the same as in Experiment 1.

Results

Three participants were removed from the analyses because they consistently made errors on ‘dix’ (10), despite the detailed instructions. The other 17 participants showed an average error rate of 5.0 %. There was no speed-accuracy trade-off, as indicated by the positive correlation between reaction time and number of errors, computed over the 16 cells of the design (8 numbers, separately for left and right responses), $r = 0.85$, $n = 16$, $p < .01$.

Overall response time of correct responses was 563 ms. As in Experiment 1, the effect of number magnitude and side of response was first evaluated in an 8 (number magnitude) x 2 (side of response) ANOVA. (The 2 x 2 x 4 design of Experiment 1 was not possible because the presence of an /s/ sound does not alternate for successive numbers.) The main effect of number magnitude was significant, $F(7, 112) = 23.50$, $MSE = 2681$, $p < .01$, mean reaction times are 640, 534, 580, 502, 527, 533, 529 and 543 ms for each magnitude in ascending order. However, more importantly, ~~T~~the interaction between number magnitude and side of response did not reach significance, $F(7, 112) = 1.63$, $MSE = 2417$, demonstrating the absence of a SNARC effect. As in Experiment 1, regression weights were computed according to the method of Fias et al. (1996). The best fitting regression line is described by the following equation: dRT = 18.34 – 0.99 (number magnitude), see also Figure 6. The coefficient of number magnitude did not differ significantly from zero, $t(16) = -0.35$, SD = 11.70.

(Figure 6 about here)

A division between the slow and fast half of the RTs for each participant indicated that the SNARC effect was absent for both the fast and the slow RTs. These are the regression lines:

Fast half: dRT = 18.5 – 1.7 number magnitude (RT = 485 ms; $t(16) = -.66$)

Slow half: dRT = 7.4 + 0.6 number magnitude (RT = 630 ms; $t(16) = .16$)

Discussion

In line with Fias (2001), we did not observe a SNARC effect in a phoneme monitoring task on number words. We did observe a- significant number magnitude effect. However, it is not a ‘regular’ semantic effect of number magnitude (increasing RTs with increasing magnitudes) as means are in the opposite direction. It can easily be explained in terms of the (in)compatibility between the stimulus and the response. For example, slow RTs to ‘trois’ are in line with our expectations as the task is to detect an /s/ sound and the participant sees the letter ‘s’ on the screen but has to give a ‘no’ response. A similar reasoning holds for the other stimuli. Th~~is~~e absence of semantic effects in Experiment 2 ~~finding~~ suggests that, similar to L1, semantic access is not needed to detect a phoneme in an L2 word. This means that the direct, non-semantic route to name number words, as proposed by Noël, Fias, and Brysbaert (1997) and Blankenberger and Vorberg (1997) and demonstrated by Fias (2001), not only exists for L1 number words but also for L2 number words.

Experiment 3

Experiment 1 and 2 showed that the SNARC effect is obtained in tasks that require semantic access (parity judgment) and not in tasks that do not require semantic access (phoneme monitoring~~word naming~~), both in L1 and in L2. This allows us to run a powerful test about whether semantic mediation is used in a simple translation judgment (yes/no) task: Participants were asked to indicate whether two presented number words were each other's translation. If this is done on the basis of straightforward word-word associations at the lexical level, we do not expect a SNARC effect. If, however, number translation always involves meaning because the meaning is activated very rapidly, as argued by Duyck & Brysbaert (2004), then we would expect to see a SNARC effect in this task.

In this experiment, participants had to perform a translation recognition task (i.e. they had to decide whether a simultaneously presented L1 and L2 word were translation equivalents or not). Consequently, the presence of a SNARC effect could only be evaluated for the 'translation' trials (in which both number words were each other's translation). In the 'no translation' trials (in which both number words were not each other's translation) we manipulated the distance between the magnitudes of the numbers. The distance effect is another robust effect found in number comparison tasks. It was first reported by Moyer and Landauer (1967). It implies that it takes longer to judge the equality of two numbers the smaller the distance between them. The presence of a distance effect is another indication for the activation of number magnitude.

According to the RHM, the translation recognition task will occur through the fast and direct lexical links between L2 and L1. This route is supposed to be faster because it does not require the extra step of semantic access. This is why the RHM also predicts that L2-L1 translation will be faster than L1-L2 translation in production. Contrastingly, if a semantic SNARC effect is obtained in this translation recognition task, this offers strong evidence that semantic mediation is involved in the translation of number words.

Method

Participants

Twenty-five Dutch speaking students (4 male, 21 female) participated in this experiment either for course credit or for financial gain. All participants were native Dutch speakers and mainly used this language in everyday life. They all learned French at school. They reported having acquired their first French words at an average age of 7.5 years (*SD* = 2.6 years). Average age was 19.9 years (*SD* = 1.6 years). Four participants were left-handed.

Instructions

Participants were instructed to judge whether pairs of Dutch and French number words were translation equivalents or not by pressing one of two response buttons. They were explicitly informed about the range of the numbers and both speed and accuracy were emphasized.

Stimuli

We used the same range of numbers as in Experiments 1 and 2. Numbers from 3 to 10 were presented as Dutch and French number words. These are the pairs ‘drie-trois’, ‘vier-quatre’, ‘vijf-cinq’, ‘zes-six’, ‘zeven-sept’, ‘acht-huit’, ‘negen-neuf’, ‘tien-dix’.

Apparatus

Apparatus was the same as in Experiments 1 and 2.

Design

The experiment had an 8 (number magnitude of the upper number) x 3 (numerical distance between the two number words: distance 0, distance 1 or distance 2) x 2 (side of response: left or right) design. All factors were manipulated within subjects.

Procedure

Participants completed two blocks. In one block right-hand responses had to be given if both words were each other’s translation and left-hand responses if both words were not each other’s translation. In the second block the response mapping was reversed. The order of both blocks was counterbalanced across participants. Each block consisted of 256 trials and was preceded with 4 practice trials. Stimuli appeared in yellow against a dark grey background in standard ERTS font, with a font size of 16 points. Each trial started with two empty rectangular frames (48.9 mm x 24.8 mm) for 300 ms, one frame appeared 2 cm above the screen center and the other 2 cm beneath the screen center. Then, a Dutch and a French number word appeared for 1300 ms in the frames, so that each Dutch number word appeared 16 times (8 times in the upper position and 8 times in the lower position) with the correct translation in the other position. As a result, each block consisted of 128 ‘translation’ trials. The other 128 trials were ‘no-translation’ trials, in which we manipulated the distance between both numbers. Each of the 26 possible number pairs with distance 1 or 2 within our stimulus range was presented 4 times, 2 times with the Dutch word in the upper position and 2 times with the Dutch word in the lower position. The number of ‘no translation’ trials was equal to the number of ‘translation’ trials by adding 24 filler trials with distance 3 between both numbers. Trials were presented in a randomized order with the restriction that no repetitions were allowed. Between trials the screen was blank for an inter-trial interval of 1500 ms.

Results

Filler trials (distance 3) were excluded from all subsequent analyses. Average error rate was 5 %. No speed-accuracy trade-off was present as indicated by the non-significant correlation between RT and error rate, computed over the 24 cells of the design (8 numbers and 3 distances: 0, 1 and 2), $r = -.32$, $n = 24$, $p = .13$.

Overall response time for correct responses was 644 ms. To evaluate the presence of a SNARC effect, an 8 (number magnitude) x 2 (side of response) ANOVA was performed on the ‘translation’ trials. The main effect of number magnitude was significant, $F\ (7, 168) = 7.97$, $MSE = 2322$, $p < .01$, as was the interaction between number magnitude and side of response ($F\ (7, 168) = 2.17$, $MSE = 1495$, $p < .05$). As in Experiments 1 and 2, regression weights were computed according to the method of Fias et al. (1996). The best fitting regression line was described by the following equation: dRT = 16.7 – 4.9 (number magnitude), see Figure 7. The coefficient of number magnitude differed significantly from zero, $t(24) = -2.56$, SD = 9.50, $p < .05$[1].

(Figure 7 about here)

To check whether the SNARC effect could be due to the longer overall RTs in Experiment 3 relative to Experiment 2, we again split the RTs in the fast and the slow half of each participant. These are the regression lines:

Fast half: dRT = 11.8 – 3.4 number magnitude (RT = 586 ms; $t(24) = -2.14$, $p < .05$)

Slow half: dRT = 32.0 – 7.9 number magnitude (RT = 728 ms; $t(24) = -3.16$, $p < .05$)

Because there were two different numbers on the screen on each ‘no-translation’ trial, SNARC analyses were impossible on these trials. Therefore we investigated the presence of a magnitude effect and a distance effect by means of an 8 (number magnitude of the upper number) by 2 (distance 1 or 2) ANOVA. Both main effects reached significance, F (7, 168) = 4.79, MSE = 2366, p <.01 and F (1, 24) = 4.70, MSE = 2861, p <.05 respectively. Mean RTs were 722, 748, 742, 746, 765, 756, 769 and 760 ms for magnitudes 3 to 10 respectively.~~Considering 3, 4, 5 and 6 as small numbers and 7, 8, 9 and 10 as large numbers, a planned comparison revealed that responses to large numbers (*M* = 715 ms, *SD* = 165 ms) were slower than responses to small numbers (*M* = 696 ms, *SD* = 154 ms), *F* (1, 24) = 26.18, *MSE* = 2032, *p* <.01.~~ Responses to distance 2 trials (*M* = 743 ms, *SD* = 167 ms) were faster than responses to distance 1 trials (*M* = 759 ms, *SD* = 164 ms).

Discussion

On translation trials, a SNARC effect was observed: Responses to small numbers were faster with the left hand and responses to large numbers were faster with the right hand. On no-translation trials, participants were slower to reject responses to numbers that were close in magnitude (distance 1) as translation equivalents than numbers that were further (distance 2) apart. This is in line with the monolingual finding that the time to compare two number magnitudes is an inverse function of the numerical distance (Moyer & Landauer, 1967). These two semantic effects provide strong evidence that the translation was not based on the fast L2-L1 word links, but involved the meaning of the number words that were presented.

General Discussion

In a series of three experiments, we showed that number translation involves access to the meaning of the numbers, even though the task can easily be done by relying on direct lexical connections between L1 and L2 words. First, we showed that access to the meaning of numbers elicits a SNARC effect for L2 number words, whereby it is easier to respond with the left hand to small numbers and with the right hand to large numbers. Then we showed that the effect is not obtained in a phoneme monitoring task, in line with the evidence showing that participants can name words even when they no longer understand the meaning of the words, suggesting the existence of a non-semantic naming route (Coltheart et al., 2001; Coltheart, 2004; Gerhand, 2001). Finally, we showed that a SNARC effect is obtained in a translation judgment task. Because the overall RT was slower in the translation task, we made sure that the SNARC effect was present for the fast response times as well. By comparing the fast RTs in the translation task to the slow RTs in the parity judgment task and the phoneme monitoring task, we can gauge the SNARC effect in the three tasks independent of overall RT. These are the findings:

Slow trials parity: dRT = 68.3 – 9.0 number magnitude (RT = 651 ms)

Slow trials phoneme: dRT = 7.4 + 0.6 number magnitude (RT = 630 ms)

Fast trials translation: dRT = 11.8 – 3.4 number magnitude (RT = 586 ms)

On the basis of these findings it is clear that the phoneme monitoring task gave rise to a different pattern of results than the two other tasks. In the phoneme monitoring task, there was no evidence whatsoever that the number magnitude had an effect on the response times: Participants were not influenced by the SNARC effect when deciding whether an L2 word contained a particular sound or not, even though this response could not be made on the basis of direct letter-sound mappings. In contrast, in the word translation task participants were influenced by the SNARC effect (and the number distance effect), even though the response could in principle be based on simple word-word associations.

The dissociation between the phoneme monitoring and the number translation task is particularly illuminating, because the phoneme monitoring task shows that the SNARC effect is not an effect that is observed on all possible number related binary decision tasks. Only tasks that recruit brain areas involved with the meaning of numbers (i.e., the areas close to the intraparietal sulcus) will produce the effect (Fias, Lauwereyns, & Lammertyn, 2001).

The present findings, in line with those of Duyck and Brysbaert (2002, 2004), provide further evidence for the claim that the Revised Hierarchical Model underestimates the importance of word meaning in translation tasks. An objection, however, might be that the results only apply to integer numbers. The advantage of numerical stimuli is that they allow us to draw on the extensive experience with this particular type of stimuli to design straightforward and valid tests of the semantic mediation hypothesis. The drawback is that the findings may be limited to numerical stimuli.

Fortunately, in parallel with our work, Sunderman and Kroll (in press) have obtained data that are very similar to ours with another type of stimuli (see also Altarriba & Mathis (1997) and La Heij et al. (1996), mentioned in the introduction). They used the translation verification task too and asked English-Spanish bilinguals whether Spanish-English word pairs were each other's translation or not (e.g., cama-bed [yes], cama-scholar [no]). There were two types of no-trials: trials with semantically related words (cama-blanket) and trials with unrelated words of the same length and frequency as the unrelated words (cama-scholar). Sunderman and Koll (in press) observed that for all proficiency levels participants took longer to say 'no' to the trials with semantically related words (cama-blanket) than to the trials with unrelated words (cama-scholar). This finding corroborates our data suggesting that meaning activation is an essential component of translation verification for all types of words (or at least all types of concrete words).

So, it looks like RHM indeed underestimates the importance of word meaning in translation tasks. Interestingly, a similar evolution can be noticed in the literature on monolingual language processing. Whereas for decades it has been assumed that the semantically mediated route was much too slow to influence lexical decision and word naming, it is now becoming increasingly clear that this view seriously underrates the importance of semantic information for those tasks (for a review, see Lupker, 2005). For instance, semantic variables have been shown to influence the naming times of words with inconsistent spelling-sound correspondences (Strain, Patterson, & Seidenberg, 1995). Similarly, variables like semantic feedback consistency have been found to influence lexical decision times (Pexman, Lupker, & Hino, 2002). So, even though there are non-semantic routes from written input to spoken output in visual word recognition (as attested by the lack of a SNARC effect in phoneme monitoring), this by no means implies that the activation of semantic information is too slow or minimal to have any impact. As soon as the non-semantic route is slightly delayed (e.g., by inconsistent mappings) or the impact of the semantic route is slightly increased (e.g., by semantic priming or by using stimuli with semantic features that are easy to activate), the impact of the semantic system can readily be observed. To some extent, this should come as no surprise, because most of the time people read words for meaning and the reason why word meaning is slow to be incorporated in models of language processing has more to do with the difficulty of implementing this variable in a computational model than with the conviction that word processing can be understood without a semantic system. We are convinced that very much the same conclusion will be reached about word translation.

References

Altarriba, J. & Mathis, K.M. (1997). Conceptual and lexical development in second language acquisition. *Journal of Memory and Language*, *36*, 550-568.

Beringer, J. (1999). Experimental Run Time System. BeriSoft Cooperation.

Blankenberger, S. & Vorberg, D. (1997). The single-format assumption in arithmetic fact retrieval. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *23,* 721-738.

Brysbaert, M. (1995). Arabic number reading: On the nature of the numerical scale and the origin of phonological recoding. *Journal of Experimental Psychology: General, 124,* 434-452.

Brysbaert, M. (1998). Word recognition in bilinguals: Evidence against the existence of two separate lexicons. *Psychologica Belgica*, *38*, 163-175.

Brysbaert, M. & Dijkstra, T. (2006). Changing views on word recognition in bilinguals. In J. Morais & G. d'Ydewalle (Eds.), *Bilingualism and second language acquisition.* Brussels: KVAB.

Cheung, H. & Chen, H.C. (1998). Lexical and conceptual processing in Chinese-English bilinguals: Further evidence for asymmetry. *Memory & Cognition*, *26,* 1002-1013.

Coltheart, M, Rastle, K., Perry, C., Langdon, R. & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108,* 204-256.

Coltheart, M. (2004). Are there lexicons? *Quarterly Journal of Experimental Psychology Section A – Human Experimental Psychology*, *57*, 1153-1171.

de Groot, A. M. B. (1992). Determinants of Word Translation. *Journal of Experimental Psychology: Learning Memory and Cognition*, *18*, 1001-1018.

Dehaene, S., Bossini, S. & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General, 122,* 371-396.

Dijkstra, A. & Van Heuven, W.J.B. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition, 5*, 175-197.

Duyck, W. & Brysbaert, M. (2002). What number translation studies can teach us about the lexico-semantic organisation in bilinguals. *Psychologica Belgica, 42,* 151-175.

Duyck, W. & Brysbaert, M. (2004). Forward and backward number translation requires conceptual mediation in both balanced and unbalanced bilinguals. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 889-906.

Fias, W., Brysbaert, M., Geypens, F. & d'Ydewalle, G. (1996). The importance of magnitude information in numerical processing: Evidence from the SNARC-effect. *Mathematical Cognition, 2,* 95-110. Available on www.cogprints.org

Fias, W. (2001). Two routes for the processing of verbal numbers: Evidence from the SNARC-effect. *Psychological Research, 65,* 250-259.

Fias, W., Lauwereyns, J. & Lammertyn, J. (2001). Irrelevant digits affect feature-based attention depending on the overlap of neural circuits. *Cognitive Brain Research, 12,* 415-123.

Fias, W. & Fischer, M.H. (2005). Spatial representation of numbers. In Campbell, J.I.D. (Ed.), *Handbook of Mathematical Cognition* (pp. 43-54). New York: Psychology Press.

Gerhand, S. (2001). Routes to reading: A report of a non-semantic reader with equivalent performance on regular and exception words. *Neuropsychologia, 39,* 1473-1484.

Gevers, W. & Lammertyn, J. (2005). The hunt for SNARC. *Psychology Science*, *47*, 10-21.

Kroll, J.F., & Dijkstra, A.F.J. (2002). The bilingual lexicon. In R.A. Kaplan (Ed.), *The Oxford Handbook of Applied Linguistics* (pp. 301-321). Oxford: Oxford University Press.

Kroll, J.F. & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language*, *33,* 149-174.

Kroll, J.F., & de Groot, A.M.B. (1997). Lexical and conceptual memory in the bilingual: Mapping form to meaning in two languages. In A.M.B. de Groot & J. F. Kroll (Eds.), *Tutorials in bilingualism: Psycholinguistic perspectives* (pp. 169-199). Mahwah, NJ: Lawrence Erlbaum Publishers.

Kroll, J. F., & Tokowicz, N. (2005). Models of Bilingual Representation and Processing: Looking Back and to the Future. In Kroll, J. F. & de Groot, A. M. B. (Eds.), *Handbook of Bilingualism: Psycholinguistic Approaches.* (pp. 531-553). New York: Oxford University Press.

La Heij, W., Hooglander, A., Kerling, R. & Van der Velden, E. (1996). Nonverbal context effects in forward and backward translation: Evidence for concept mediation. *Journal of Memory and Language, 35*, 648-665.

Lorch, R.F., Jr. & Myers, J.L. (1990). Regression analyses of repeated measures data in cognitive research. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *16*, 149-157.

Lupker, S.J. (2005). Visual word recognition: Theories and findings. In Snowling, M. & Hulme, C. (Eds.), *The science of reading: A handbook.* (pp. 39-60). Oxford, UK: Blackwell.

Moyer, R.S. & Landauer, T.K. (1967). Determinants of reaction-time for digit inequality judgments. *Bulletin of the Psychonomic Society, 1,* 167-168.

Noël, M.-P., Fias, W. & Brysbaert, M. (1997). About the influence of presentation format on the retrieval of arithmetic facts. *Cognition, 63*, 335-374.

Pexman, P.M., Lupker, S.J. & Hino, Y. (2002). The impact of feedback semantics in visual word recognition: Number of features effects in lexical decision and naming tasks. *Psychonomic Bulletin & Review, 9,* 542-549.

Sholl, A., Sankaranarayanan, A. & Kroll, J.F. (1995). Transfer between picture naming and translation: A test of asymmetries in bilingual memory. *Psychological Science, 6,* 45-49.

Strain, E., Patterson, K. & Seidenberg, M.S. (1995). Semantic effects in single word naming. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21,* 1140-1154.

Sunderman, G. & Kroll, J.F. (in press). First language activation during second language lexical processing: An investigation of lexical form, meaning and grammatical class. *Studies in second language acquisition, 28.*

van Hell, J. G., & de Groot, A. M. B. (1998). Conceptual Representation in Bilingual Memory: Effects of Concreteness and Cognate Status in Word Association. *Bilingualism: Language and Cognition, 1*, 193-211.

Van Wijnendaele, I. & Brysbaert, M. (2002). Visual word recognition in bilinguals: Phonological priming from the second to the first language. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 616-627.

Footnotes

1. As expected, the position of the L1 word on the screen did not make a difference for the presence of the SNARC effect. The coefficient of number magnitude for the trials with L1 in the upper position (dRT = 19.38 - 4.92 (number magnitude)) did not differ significantly from the coefficient of number magnitude for the trials with L2 in the upper position (dRT = 17.29 – 5.21 (number magnitude)), $t(24) = 0.14$.

Figure captions

~~Figure 1. The Revised Hierarchical Model of bilingual memory (Kroll & de Groot, 1997). Solid lines represent stronger links than dotted lines. L1 = first language; L2 = second language.~~

Figure ~~2~~1. Revised Hierarchical model, taking into account the evidence that there are no separate lexicons for L1 and L2. The English word 'duty' and its Dutch translation 'plicht' are part of the same lexicon and are connected to each other with asymmetric weights (stronger from L2 to L1 than from L1 to L2). Both words activate overlapping semantic features (though not all features need to be shared as the meanings of translation equivalents are rarely completely the same). The connections between L1 words and semantic features are stronger than those between L2 words and semantic features.

Figure ~~3~~2. The connectionist model as proposed by Duyck and Brysbaert (2004), with varying semantic overlap and differently weighted lexico-semantic and intralexical connections. Solid lines represent stronger links than dotted lines. Depicted words and semantic representations are illustrative examples for Dutch-English bilinguals. L1 = first language, L2 = second language.

~~Figure 4. Interaction response side by number magnitude (Experiment 1).~~

Figure ~~5~~3. Observed data and regression line representing RT differences between right-hand and left-hand responses as a function of number magnitude in Experiment 1. dRT = 35.62 – 4.89 (number magnitude).

Figure ~~6~~4. Observed data and regression line representing RT differences between right-hand and left-hand responses as a function of number magnitude in Experiment 2. dRT = 18.34 – 0.99 (number magnitude).

Figure ~~7~~5. Observed data and regression line representing RT differences between right-hand and left-hand responses as a function of number magnitude in Experiment 3. dRT = = 16.7 – 4.9 (number magnitude).

~~Figure 1~~

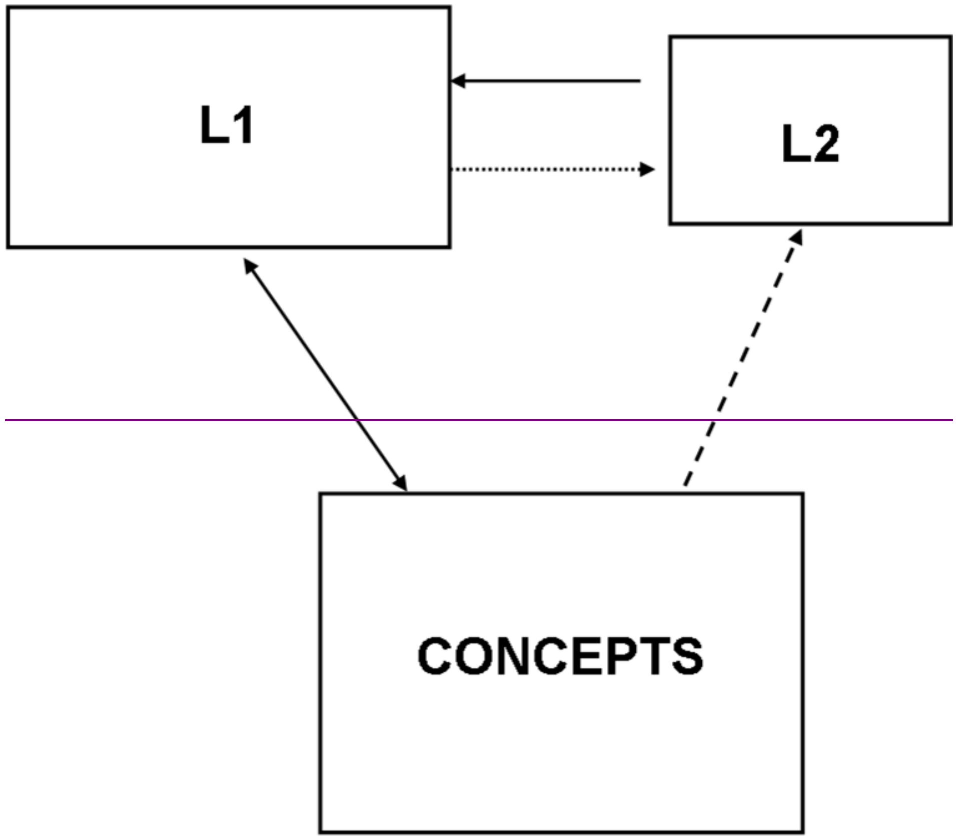


Figure ~~2~~1

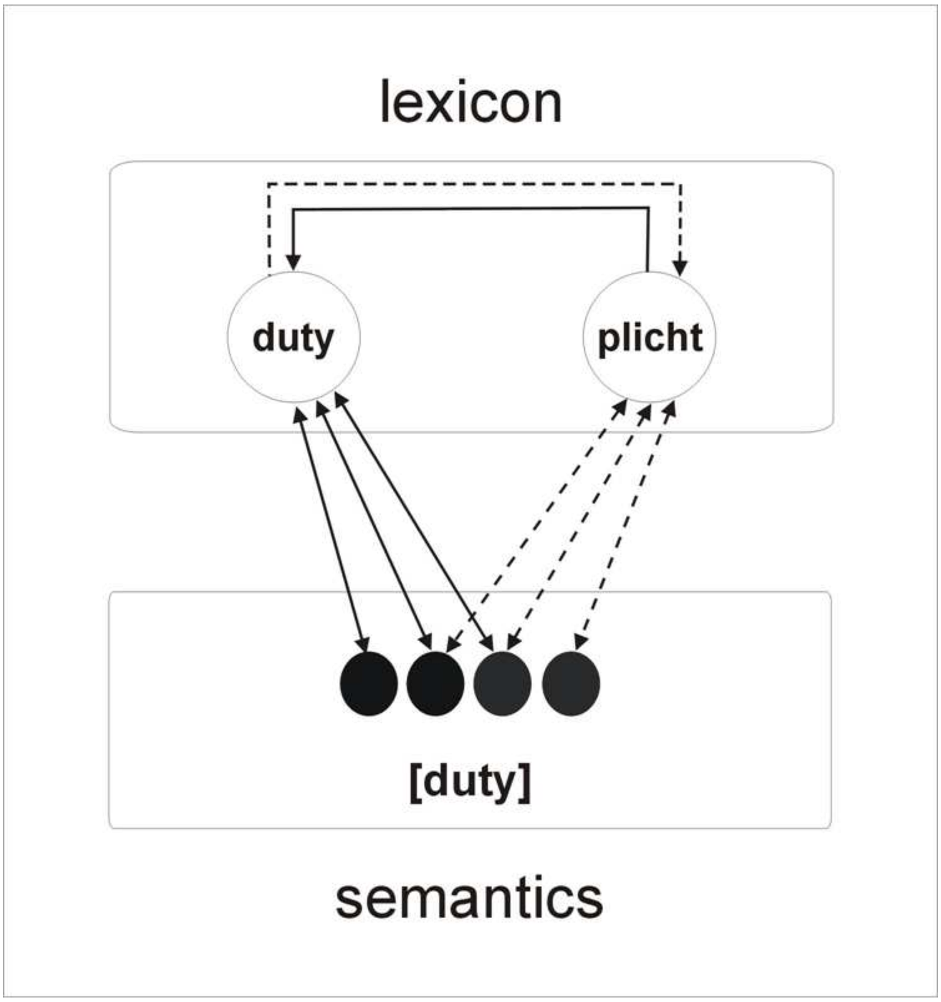
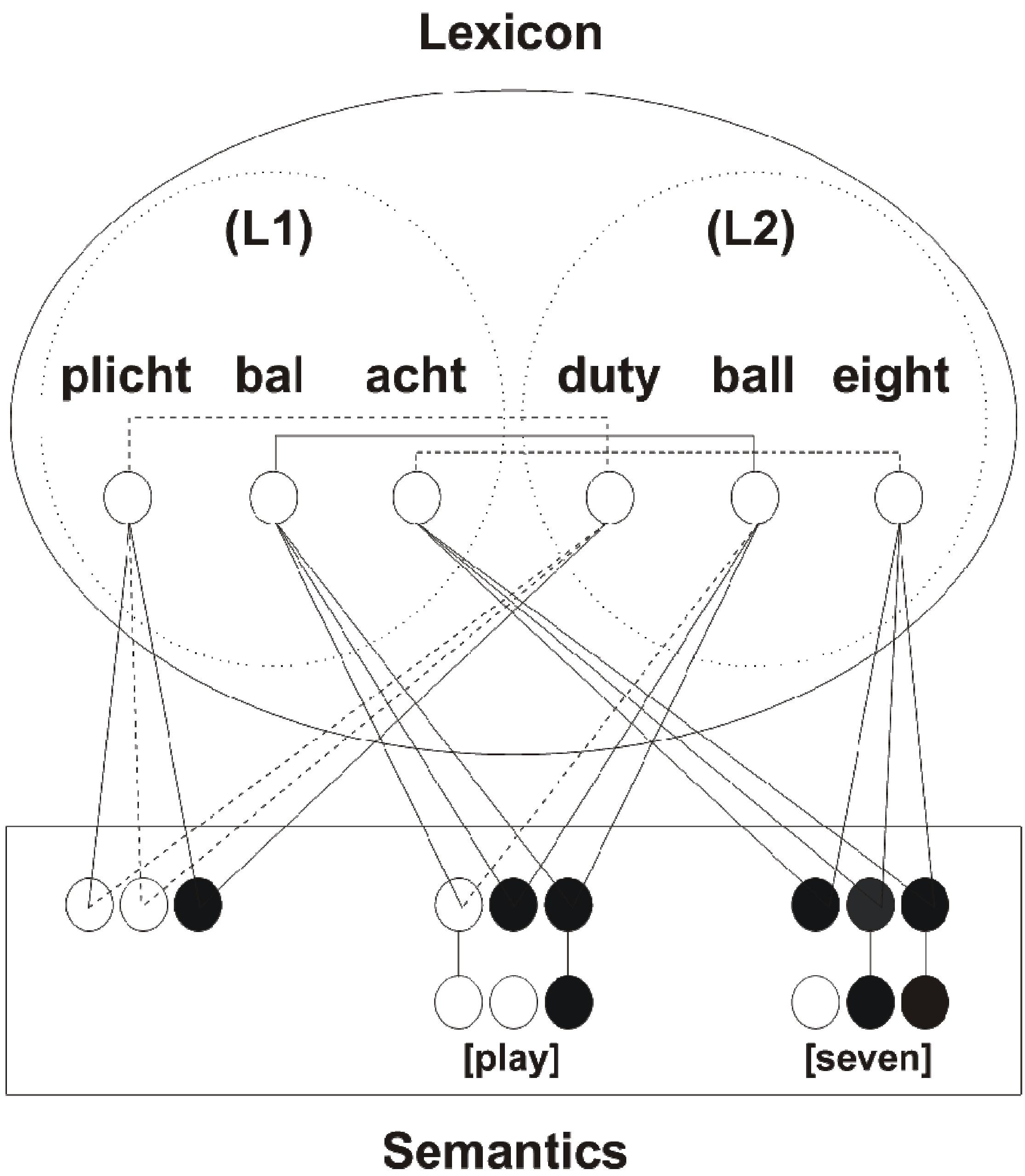
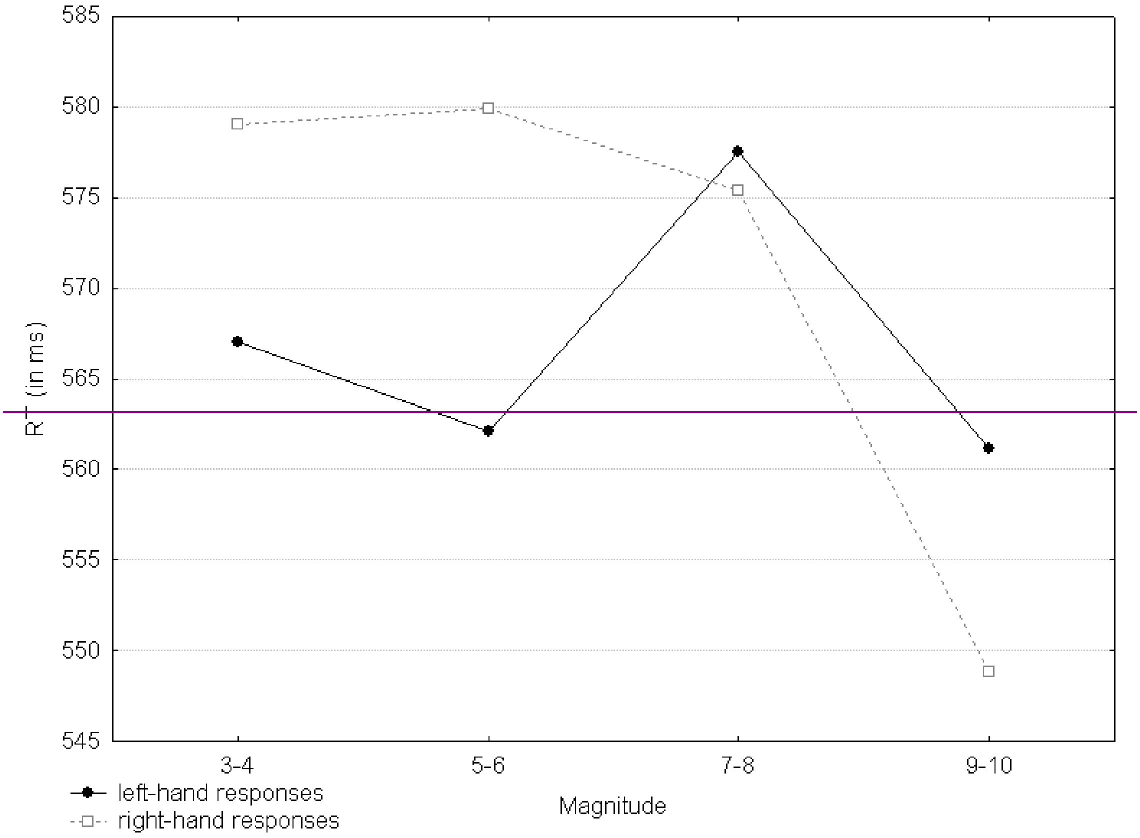


Figure ~~3~~2


Lexicon
(L1)
(L2)
plicht
bal
acht
duty
ball
eight
[play]
[seven]
Semantics

~~Figure 4~~


585
580
575
570
565
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555
550
545
RT (in ms)
3-4
5-6
7-8
9-10
Magnitude
left-hand responses
right-hand responses

Figure ~~5~~3

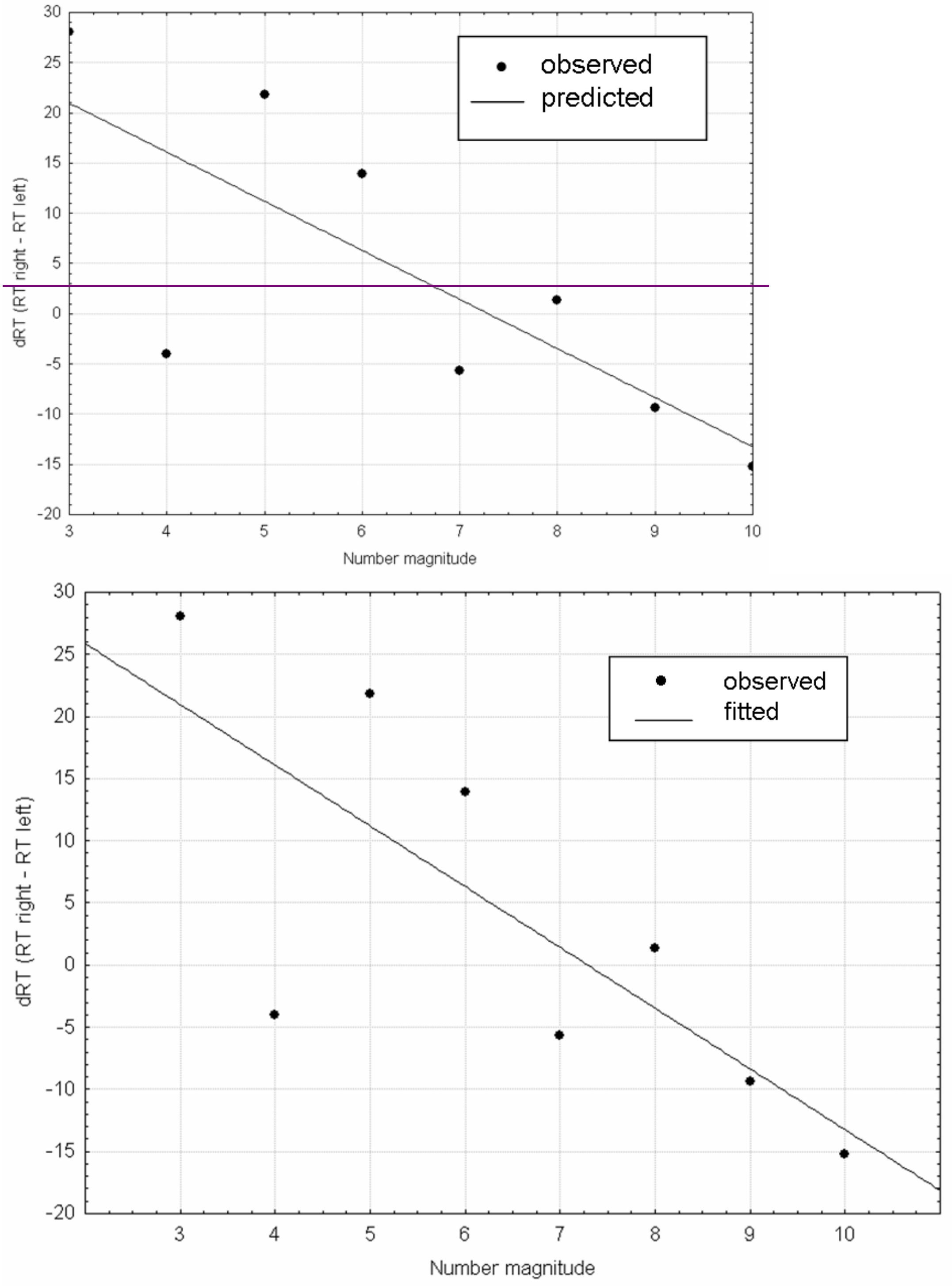

observed
predicted
dRT (RT right - RT left)
Number magnitude
observed
fitted
dRT (RT right - RT left)
Number magnitude

Figure ~~6~~4

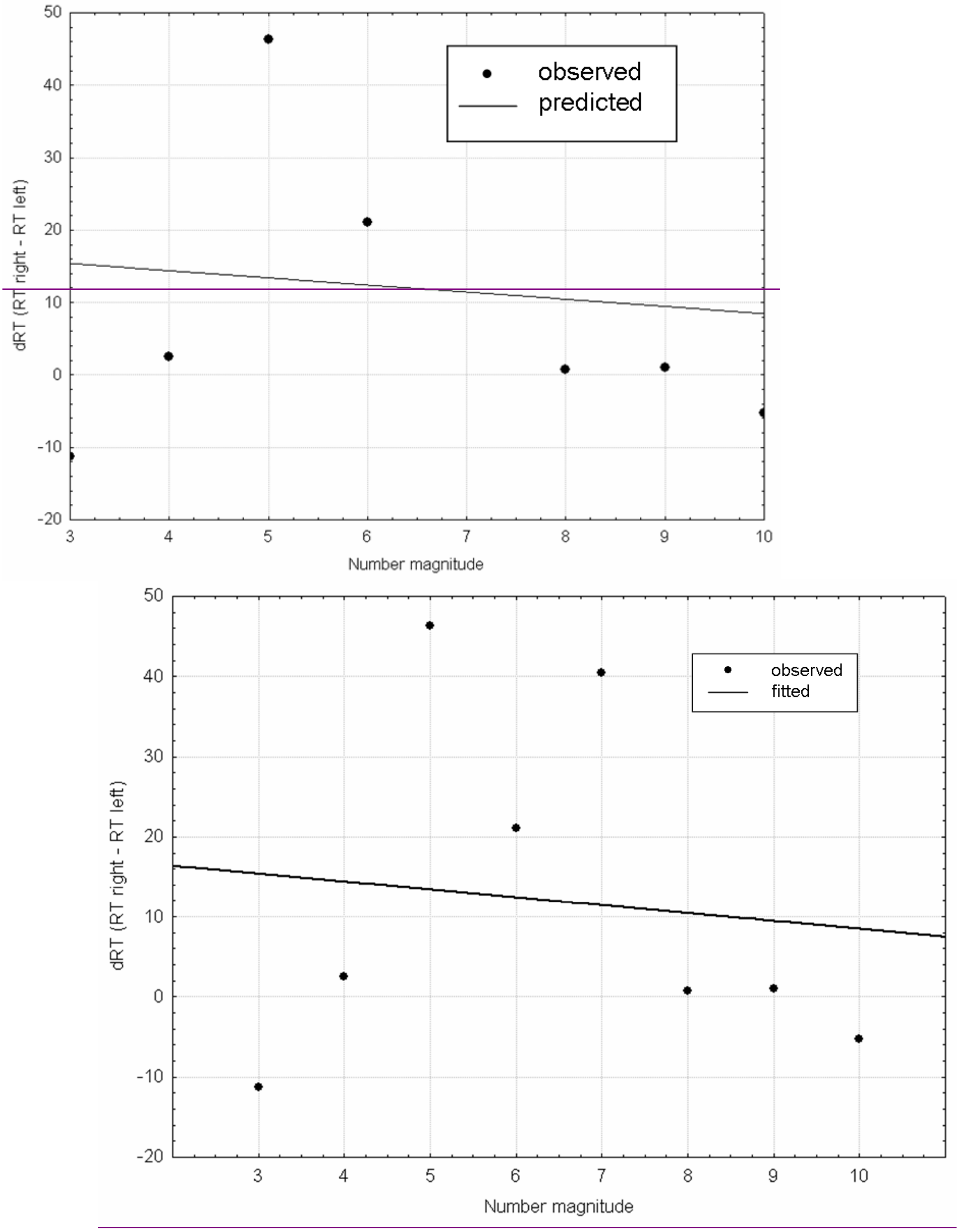
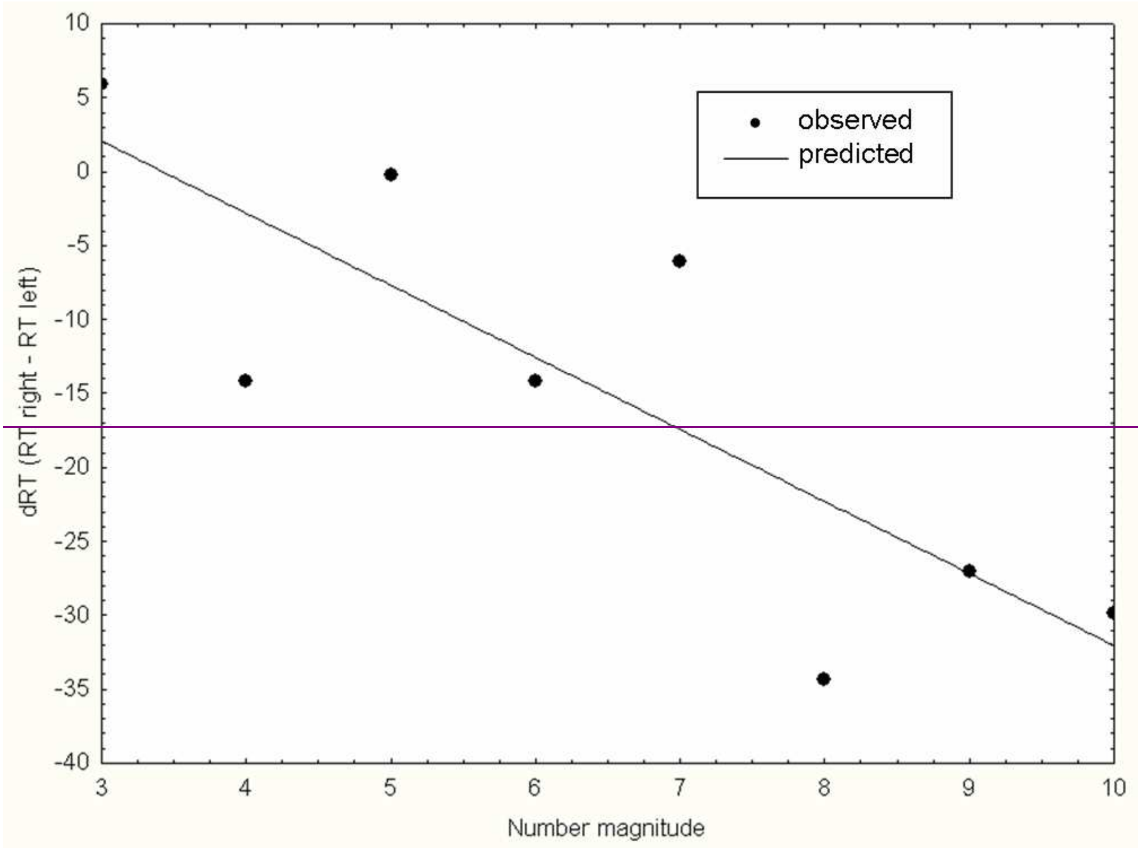
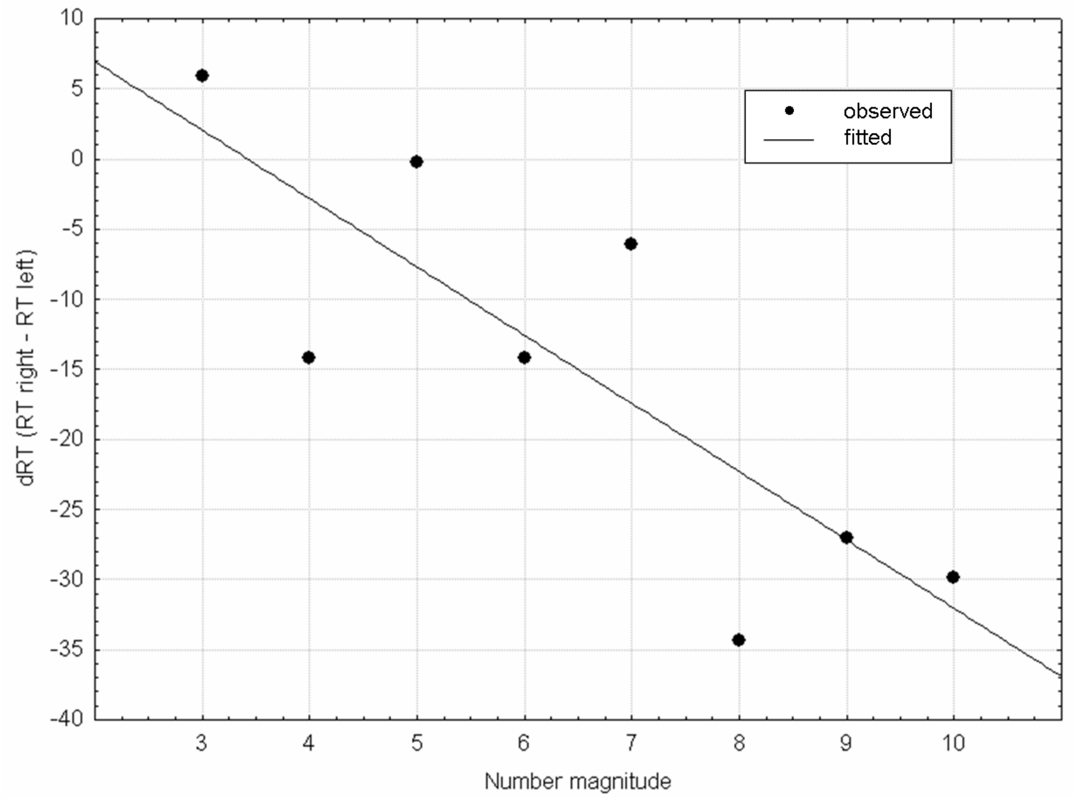

observed
predicted
dRT (RT right - RT left)
Number magnitude
observed
fitted
dRT (RT right - RT left)
Number magnitude

Figure ~~7~~5



10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
dRT (RT right - RT left)
observed
predicted
3
4
5
6
7
8
9
10
Number magnitude



10
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dRT (RT right - RT left)
observed
fitted
3
4
5
6
7
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10
Number magnitude